IROS 2009 Workshop

Network Robot Systems: Network Robot Systems: Network Robot Services for the Elderly

October 15, 2009
St. Louis, USA

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Combination of Distributed Camera Network and Laser-based 3D Mapping for Urban Service Robotics

Institut de Robòtica i Informàtica Industrial

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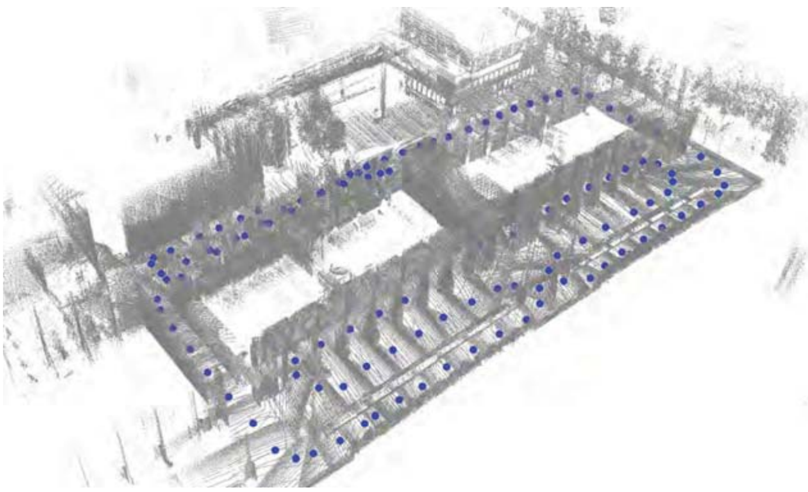
IROS'09 Workshop on Network Robot Systems
St. Louis, Missouri

October 2009

Outline

- Introduction
- Laser-based 6DOF SLAM
- From range maps to traversability maps
- From range maps to camera network calibration



Introduction

- A much needed step, usually neglected in SLAM implementations, is to compute maps useful for robot path planning and navigation.
- In this presentation we show how SLAM results are used to create useful maps for the URUS project.

Introduction: Overview

Data acquisition

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ICP alignment

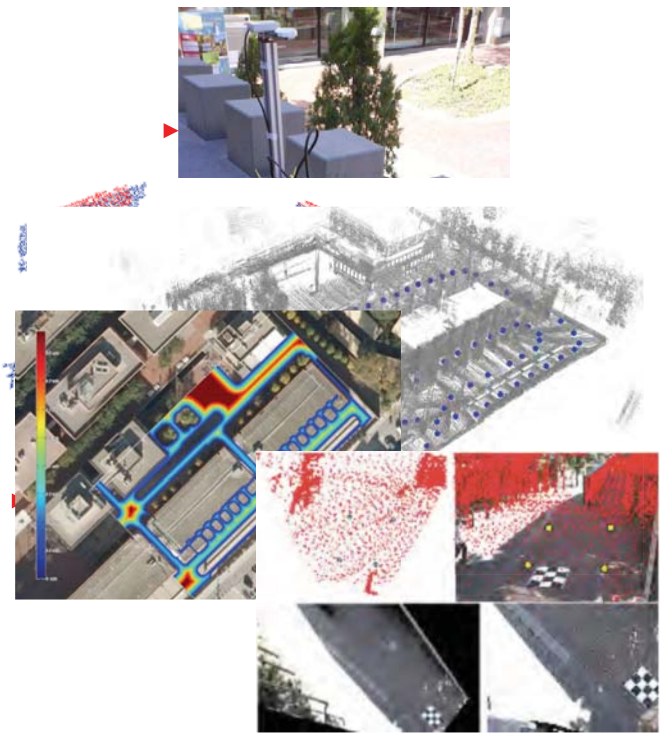
▼

6DOF SLAM

▲ ▲

Traversability map

Camera network calibration



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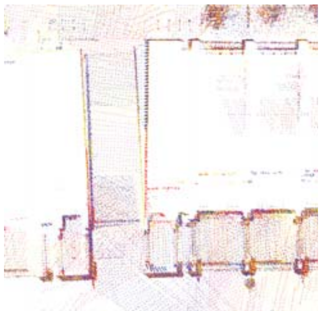
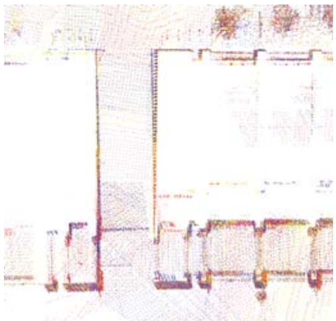
Scan matching

- Iterative Closest Point over consecutive range scans
  - ANN: Approximated Nearest Neighbor Search (Mount and Arya, 1997)
    - Euclidian space
    - Very efficient (divides the space using kd-trees)
  - NNSS: Nearest Neighbor Search in Spherical Space (Minguez et al., 2006)
    - Divide the space using spherical coordinates.
    - Gives more weight to the rotation.
    - Higher computational cost



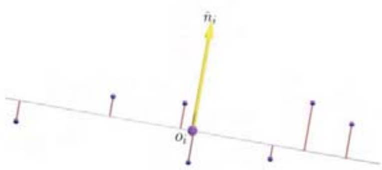


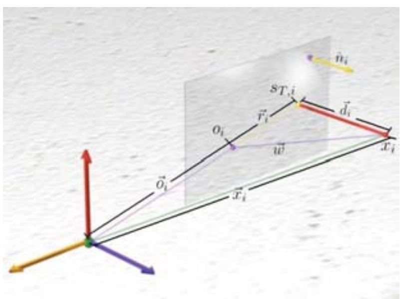
Scan matching

- Biota et al. Proposed a metric for the registration step which compensate translation and rotation.

$$d_p^{ap}(p_1, p_2) = \sqrt{\|\delta\|^2 - \frac{\|p_1 \times \delta\|^2}{k}} \qquad k = \|p_1\|^2 + L^2$$

- We combined Biota's icra06 metric with a correspondence search on the Euclidean space.
- We proposed a hierarchical new correspondence search strategy:
  - Using a point-to-plane strategy at the highest level and a point-to-point metric at finer levels.

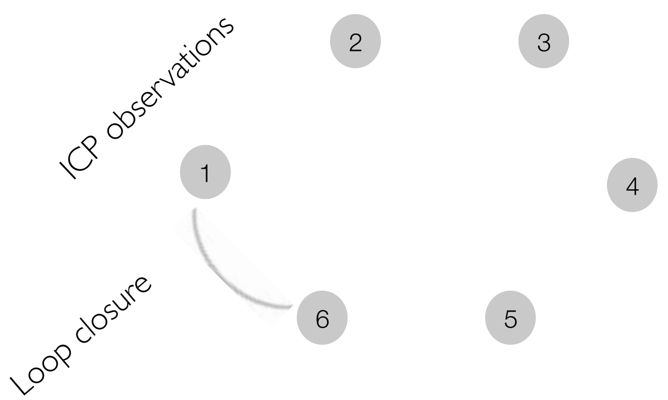


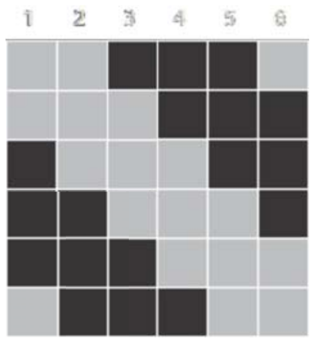


6DOF SLAM

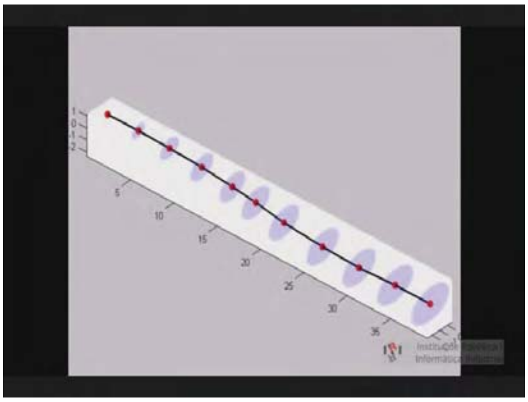
- Pose SLAM: *Eustice06, Ila09*
  - Delayed-State Extended Information Filter.
  - Estimates a state vector containing the history of poses.

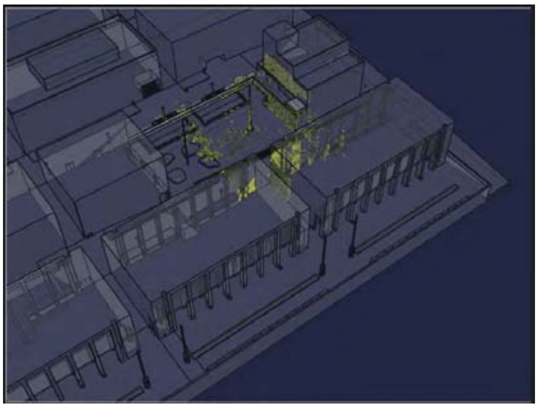
$$p(\mathbf{x}) \sim \mathcal{N}(\mathbf{x} : \boldsymbol{\mu}, \boldsymbol{\Sigma}) \sim \mathcal{N}^{-1}(\mathbf{x} : \boldsymbol{\eta}, \boldsymbol{\Lambda})$$



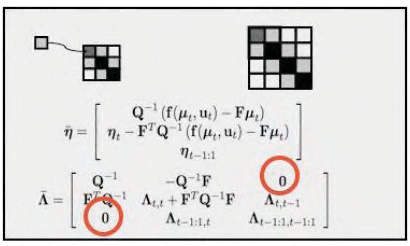


6DOF SLAM

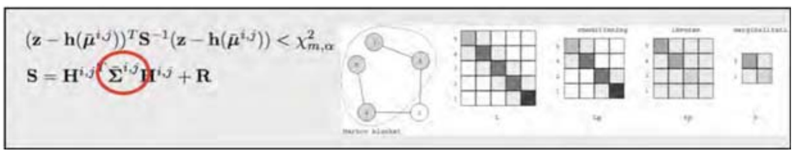




State augmentation:

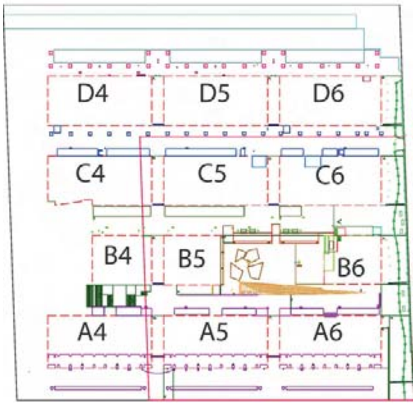


Loop closure:



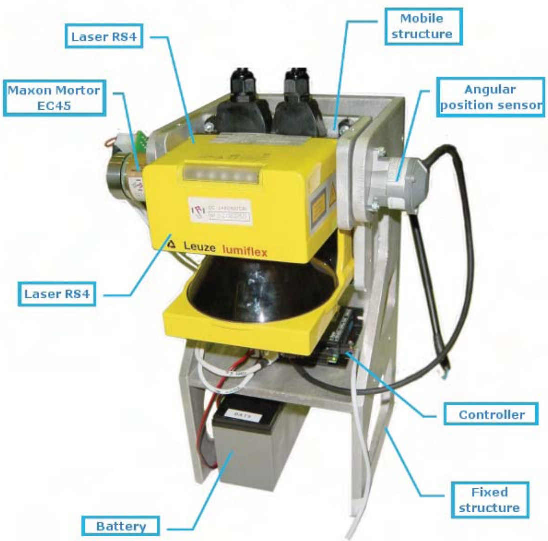
Experimental Site

- Over 15,000 sq. meters
- Several levels and underpasses
- Poor GPS coverage
- Sunlight exposure severely subject to shadows
- Moderate vegetation
- Several points with aliasing
- Large amount of regularity from building structures



Experimental setup: Laser 3D

- 3D point clouds with ranges up to 30 meters
- 76,000 points per cloud
- Sensor noise level is ±5 cm in depth estimation

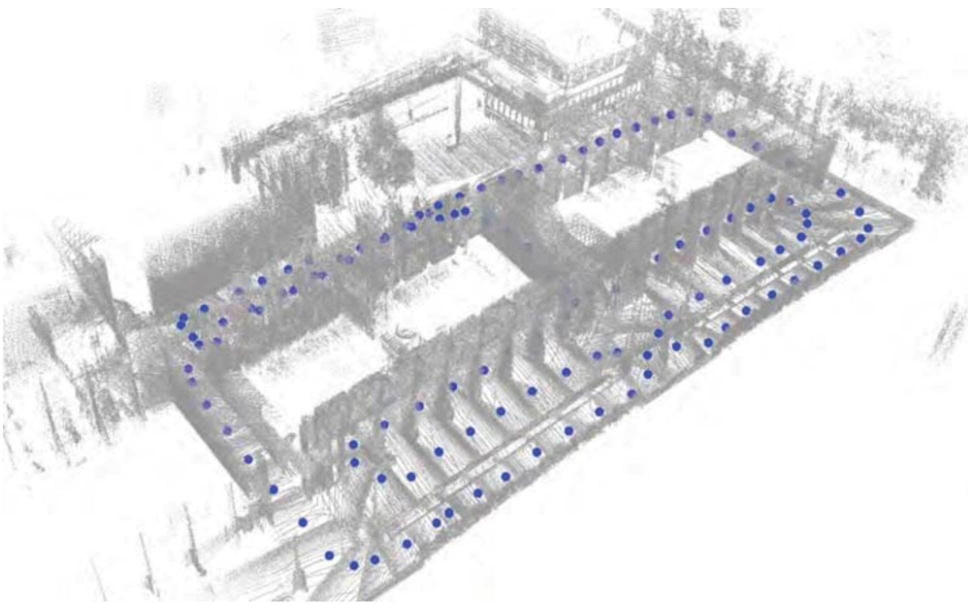


Experimental setup: Robotic platform

- Pioneer 3AT robot
- Other sensors: GPS, INS

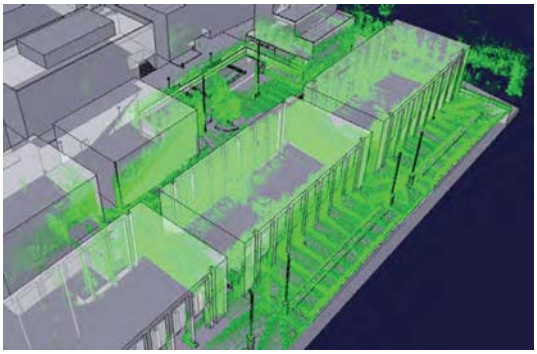
Laser 3D

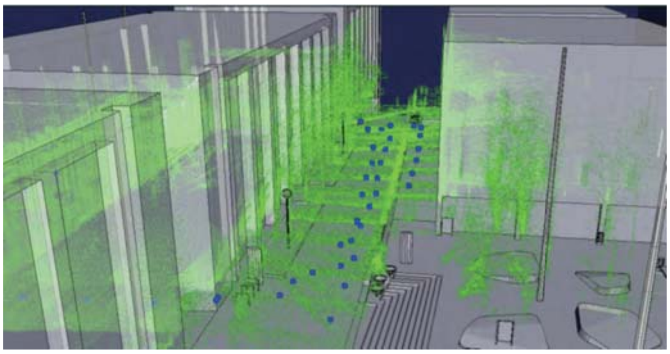
3D Mapping results



3D Mapping results

- Results are compared to manually built CAD model.
- The CAD model was made using geo-referenced information.

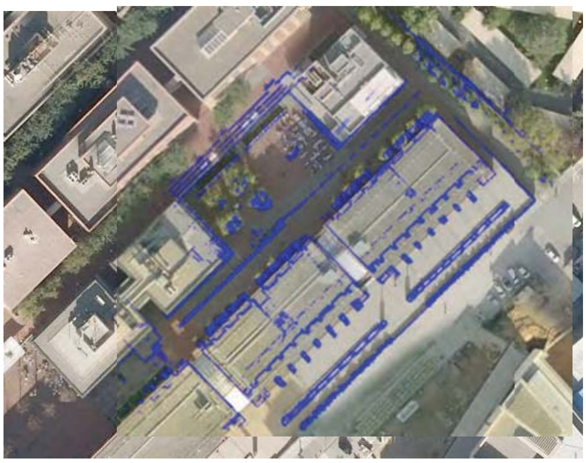




Traversability maps

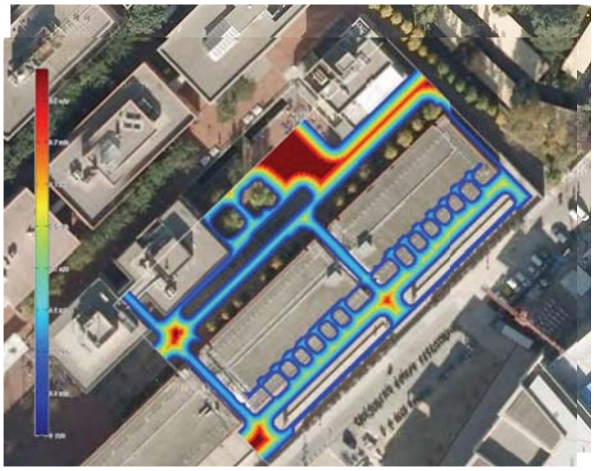
- 2D grid layer. Each cell indicates maximum linear velocity.

  1. Horizontal cut at robot laser height to create 2D layer.
  2. Morphological operations to enlarge obstacles to produce a binary grid map.

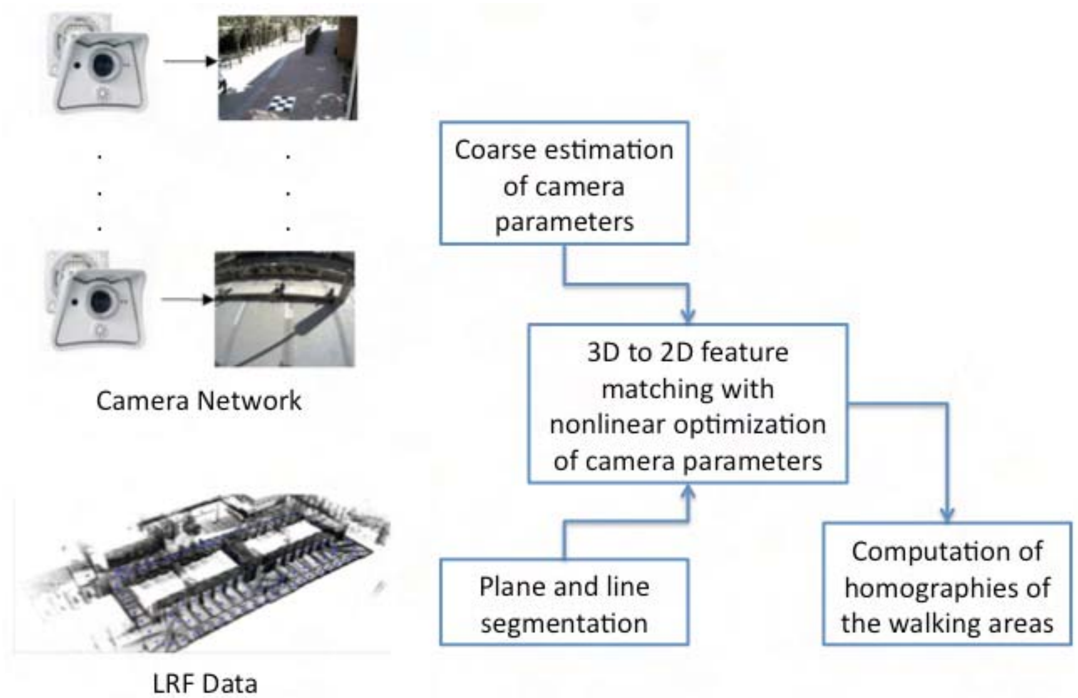


Traversability maps

- 2D grid layer. Each cell indicates maximum linear velocity.
  1. Horizontal cut at robot laser height to create 2D layer.
  2. Morphological operations to enlarge obstacles to produce a binary grid map.
  3. For each robot configuration in the grid, compute the set of admissible actions that do not produce a collision.
  4. And select the minimum for all orientations of the maximum linear velocities at each xy location.



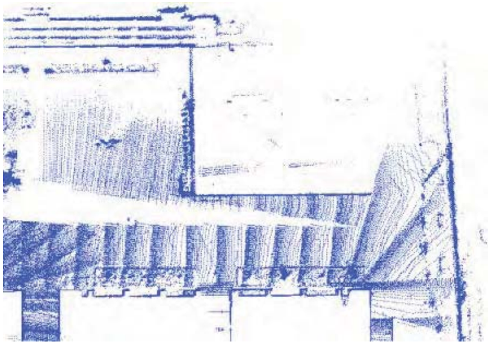
Camera Network Calibration



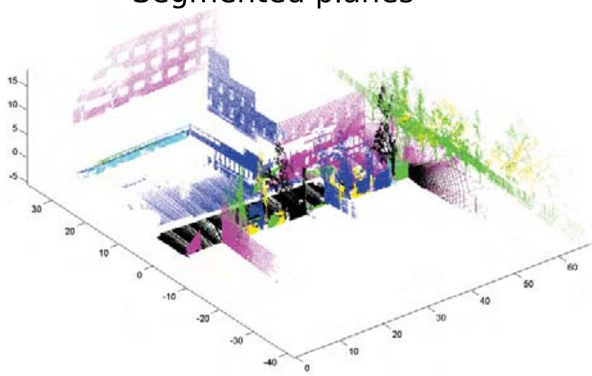
Plane and line segmentation

- A very efficient graph-based region growing algorithm is used to segment planes from the range map.

Unsegmented map (top view)

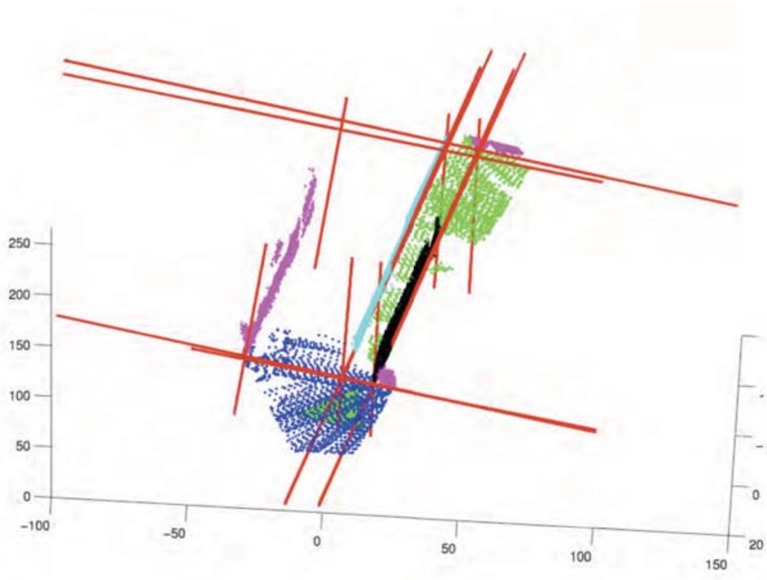


Segmented planes



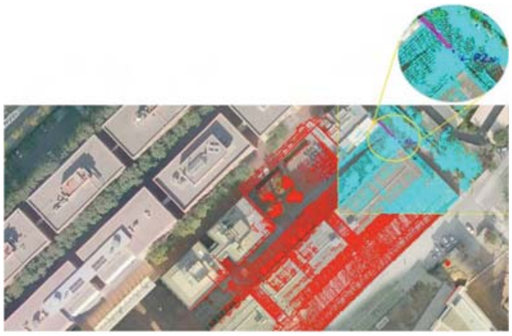
Plane and line segmentation

- Planes are intersected to extract line segments.



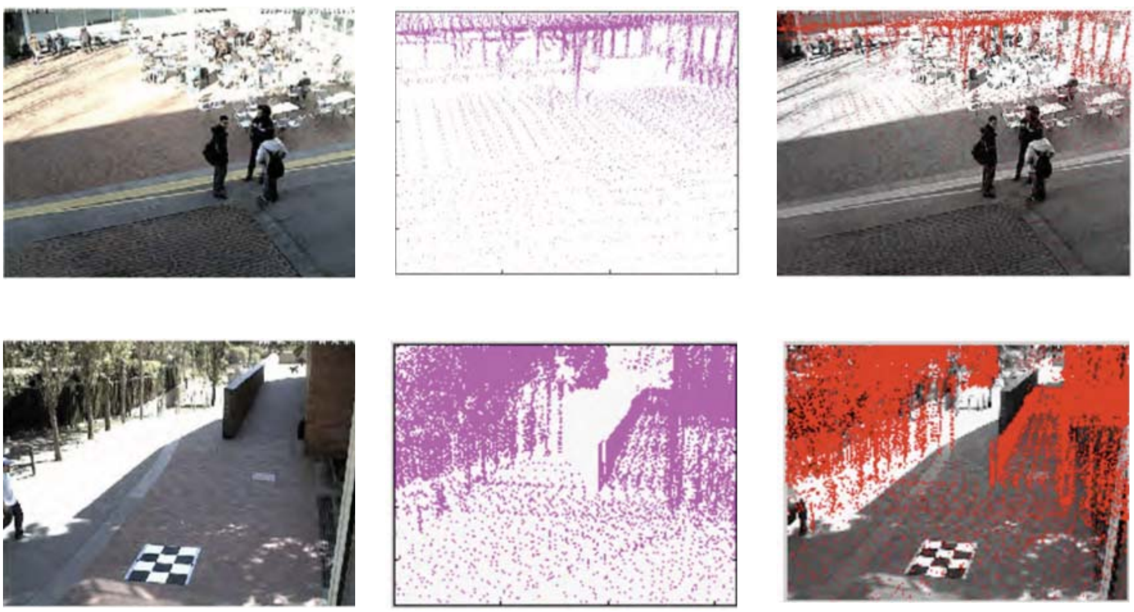
Coarse calibration

- User interaction with a GUI:
- Select initial camera location, viewing direction and field of view.



$$P(\vartheta_j) = K[R|t]$$

Coarse calibration

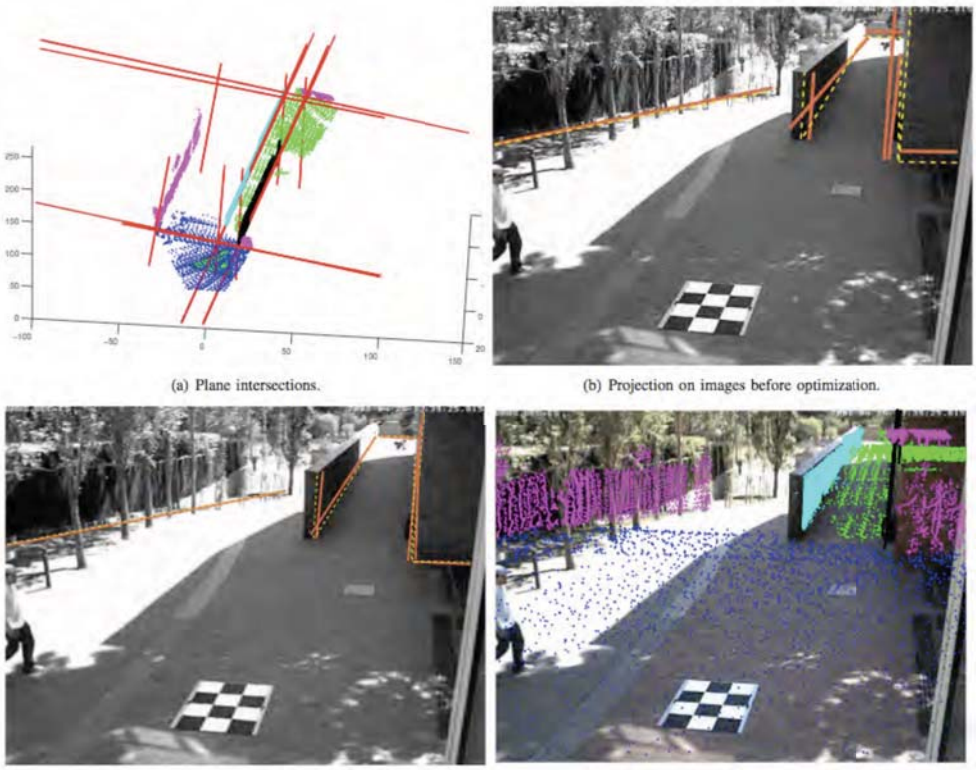


Nonlinear optimization

- 3D to 2D line matching with nonlinear optimization
- Iterate over each of the camera parameters
- Minimize distance between laser projected points and image points on the matching lines

$$\hat{\vartheta}_j = \arg\min_{\vartheta_j} \sum_i \left\| m_i - h\left(P(\vartheta_j) \cdot M_i\right) \right\|^2$$

Nonlinear optimization

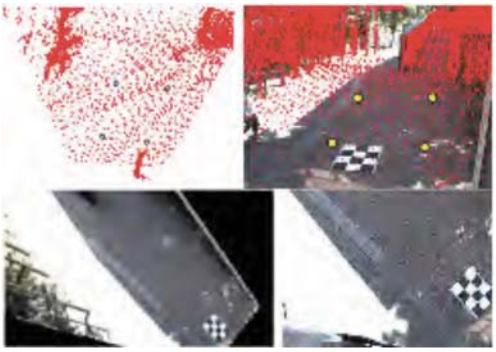


(a) Plane intersections. (b) Projection on images before optimization.

(c) Projection on images after optimization. (d) Final projection of the segmented LRF data.

Homographies of the walking areas

- Use the calibration results to compute homographies of the walking areas
- These can be used to measure traveling distances or traveling speed of robots and people



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